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FILTER CANISTER FLOW DISTRIBUTION VISUALIZATION EXPERIMENTS (U)

by

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ABSTRACT

A colorimetric method of visualizing the airflow distribution inside a charcoal filter canister was developed to study the new plastic canister design. The method uses silica gel (of the same size as the charcoal used in the canister) coated with an acid/base dye which changes colour from yellow to a dark blue in the presence of a base. The depth of the reacted dye is a direct representation of the flowrate. A technique to observe the cross-section of the canister was developed, and canisters were subjected to various flowrates in different configurations. It was found that the current plastic canister design is sound, and that its uniform flow distribution will ensure optimal use of the charcoal and thus the highest efficiency. The retainer designs evaluated (the current C2 canister retainer and that of the new plastic canister) did not seem to have an effect on the flow distribution.

RÉSUMÉ

Une méthode colorimétrique de visualisation de la distribution de l'écoulement d'air à l'intérieur d'une cartouche filtrante au charbon a été développée pour étudier le nouveau design de la cartouche plastique. La méthode comprend l'utilisation de granules de silice (de même grosseur que les granules de charbon de la cartouche) revêtus d'une teinture acide/base qui tourne du jaune au bleu. La profondeur du changement de couleur du lit de silice est une représentation directe de la quantité d'air passée à travers. Une technique pour observer la coupe transversale de la cartouche a été mise au point et diverses configurations de cartouche ont été soumises à deux régimes d'écoulement d'air. On a trouvé que le design actuel de la cartouche plastique est sain et que l'écoulement d'air est uniforme, ce qui garantit l'utilisation optimale du charbon et du même fait l'efficacité maximale. Le design des pièces de rétention évaluées (celui de la cartouche C2 et de la nouvelle cartouche en plastique) n'ont pas semblé affecter la distribution d'air.

EXECUTIVE SUMMARY

A colorimetric method of visualizing the airflow distribution inside a charcoal filter canister was developed. The aim of the experiments carried out with this method was to ensure the adequacy of a new plastic canister design. The method uses silica gel of the same size as the charcoal used in the canister, coated with an acid/base dye which changes colour from yellow to a dark blue in the presence of a base. A mixture of air and diethyl amine is passed through the canister, and its reaction with the dye causes it to turn blue immediately. A cross-section of the silica gel bed shows the transition between the reacted dye and non-reacted dye. The interface line gives an indication of airflow distribution inside the charcoal bed. The contrast obtained between the dye's original colour and the reacted colour was found to be dependent on the appropriate relative humidity pre-conditioning of the canister.

Experiments were carried out to assess the general flow characteristics of the current plastic canister design, and the effect of the retainer design. It was found that the current plastic canister design is sound, and that its uniform flow distribution will ensure optimal use of the charcoal and thus the highest efficiency. The retainer designs evaluated (the current C2 canister retainer and that of the new plastic canister) did not seem to have an effect on the flow distribution. The plastic canister design was found to be efficient and thus will not require modification.

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1.0 INTRODUCTION

DREO is currently developing a plastic canister which will eventually replace the current aluminum based C2 NBC canister. The C2 canister design has been well documented and its performance is well known. The plastic canister, on the other hand, is relatively new in the field of military NBC canisters, and its behaviour under military test regimen is still under investigation. The change from aluminum to plastic is a natural progression which was made possible by advances in polymer technology. The filter media, i.e. the particulate, charcoal fines and charcoal filters, are still the same as in the C2. The major difference is in the number and shape of the structural components. Because of this, the performance of the plastic canister can not be simply interpolated from C2 canister data.

In order to help in the development of the plastic canister, it was decided to investigate the effect of these design changes on the airflow patterns inside the all-important charcoal bed. The implications of improper flow distribution are far reaching in terms of its life-saving characteristics as improper flow distribution will reduce the filtration life of a canister. A larger amount of charcoal may then be required to compensate for the lack of performance. The larger amount of charcoal will increase the cost of the canister as well as the breathing resistance.

This study was aimed at providing a simple means of obtaining a visual indication of the airflow patterns inside the canister, and more particularly inside the charcoal bed. This qualitative method is based on the use of an acid/base dye. The original intent was to use coloured silica gel (Drierite which discolours from light blue to beige with humidity) in lieu of charcoal in the canister. The passage of a flow of moist (ambient) air through it would eventually discolour the Drierite granules in the flow direction. Then, a cross-section through the middle would reveal the airflow distribution through the canister. It was thought that the rate of colour change would be proportional to the flow rate, given a uniform moisture distribution in the air used. Therefore the depth of the colour change from the top would give a relative appreciation of the airflow distribution. Preliminary trials seemed to confirm this, but there was too little contrast between the used (beige) and unused (light blue) silica gel to see the flow profile. The change in colour was too gradual and the colours too light to provide a clear demarkation of the flow profile.

This idea was carried further and it was decided to use a different dye which would offer more contrast. The dye chosen was 3',3'',5',5''-tetrabromophenolphthalein ethyl ester (TBPE) which is used in detector paper (1). In its original state, it is light yellow, and reacts with a base (diethylamine in this case) to create a dark blue colour. Figure 1 shows the reaction of the TBPE

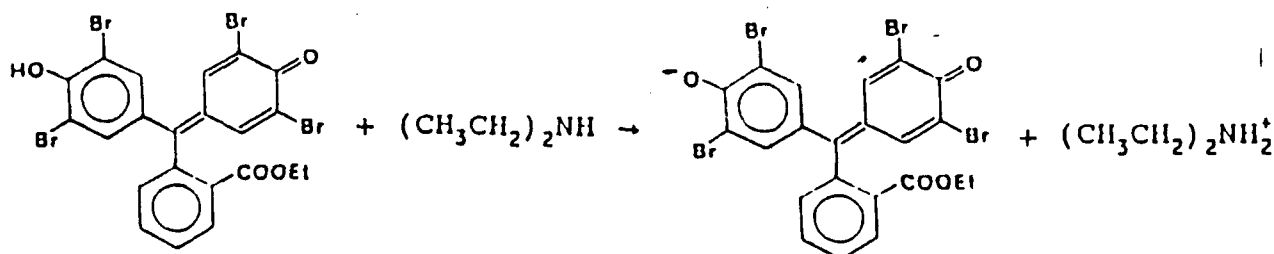


Figure 1: Dye Reaction

create a dark blue colour. Figure 1 shows the reaction of the TBPE with diethylamine.

The removal of the phenolic proton is an acid/base reaction. The blue colour is caused by the resonance stabilization of the charge in the highly conjugated ring system. This dye was applied to silica gel of the same mesh size as the charcoal which will be used in the plastic canister.

2.0 EXPERIMENTAL

2.1 Instrumentation.

The experiments were performed with the DREO Canister Test Assembly apparatus (2). The flow, temperature and humidity of the air were controlled by a Miller Nelson Research Inc., model HCS-301, Flow-Temperature-Humidity Control System. The amine flow was controlled by a Cole-Parmer Microprocessor Pump Drive and the amine temperature was controlled by a Superior Electric Co. USA, Powerstat L 10C variable autotransformer.

2.2 Impregnation of silica gel with TBPE.

A batch of 1.3 kg of silica gel of mesh 12-30 was placed in a 4 litre beaker equipped with a mechanical stirrer (glass shaft, Teflon blade). With stirring at 300 rpm, 1.6 litre dichloromethane (Mallinckrodt, Accusolv grade) were slowly added. A solution of 1.30 g TBPE in 50 ml dichloromethane (1.00 g TBPE \approx 1.000 kg silica gel) was then added and the mixture stirred at 300 rpm for 2 hours. The mixture was then stripped in 500 ml portions on a rotary evaporator followed by drying under high vacuum (4-6 hours). A total of three batches were prepared for the experiments. The TBPE was prepared by Anachemia, Canada, according to reference 1.

2.3 Method.

A transparent plastic canister was used in the experiments so as to allow the dye colour change to be viewed from the outside, without disassembling the canister. Annex A (Figures A-1 to A-5) shows the plastic canister in various states of assembly. The canister was modified with a thin, vertical transparent wall dividing the silica gel bed into two halves (see Annex A, Figure A-5). This wall had little or no effect on the flow distribution within the bed, as discussed in section 3.0. The canister was filled with 170 cc of the impregnated silica gel using the normal canister filling equipment. The canister was assembled, and challenged with a mixture of air and diethylamine. After the experiment the particulate filter, the retainer and the fines filter were removed and half of the silica gel bed was carefully emptied without destroying the other half. Thus, the flow pattern in a cross section of the canister could be visualized. The experiments were performed with the canister placed in the test chamber of the DREO Canister Test Assembly as shown in Annex A, Figure A-6. Figure 2, below, shows a schematic of the experimental set-up.

The peristaltic pump controls the diethylamine flow into the mixer in the DREO Canister Test Assembly. The heater and the thermocouple are connected to a metal plate in the bottom of the mixer controlling the evaporation of the diethylamine. Air is then added and mixed with the evaporated diethylamine.

The mixture of air and diethylamine flows through the canister. The diethylamine reacts with the TBPE on the silica gel changing the colour from yellow to blue. The relative humidity (RH) of the outgoing air is measured by a hygrometer.

Pictures of the instrumentation and the experimental set-up are shown in Annex A.

2.3.1 Preconditioning

The canisters were preconditioned in three ways:

- #1) For experiments 1-10 and 13-14 the canisters were preconditioned for 17-26 hours at 80 % RH.
- #2) For experiments 11-12 and 15-18 the canisters were preconditioned for 5-6 hours at 80 % RH.
- #3) Experiments 19-24 were not preconditioned.

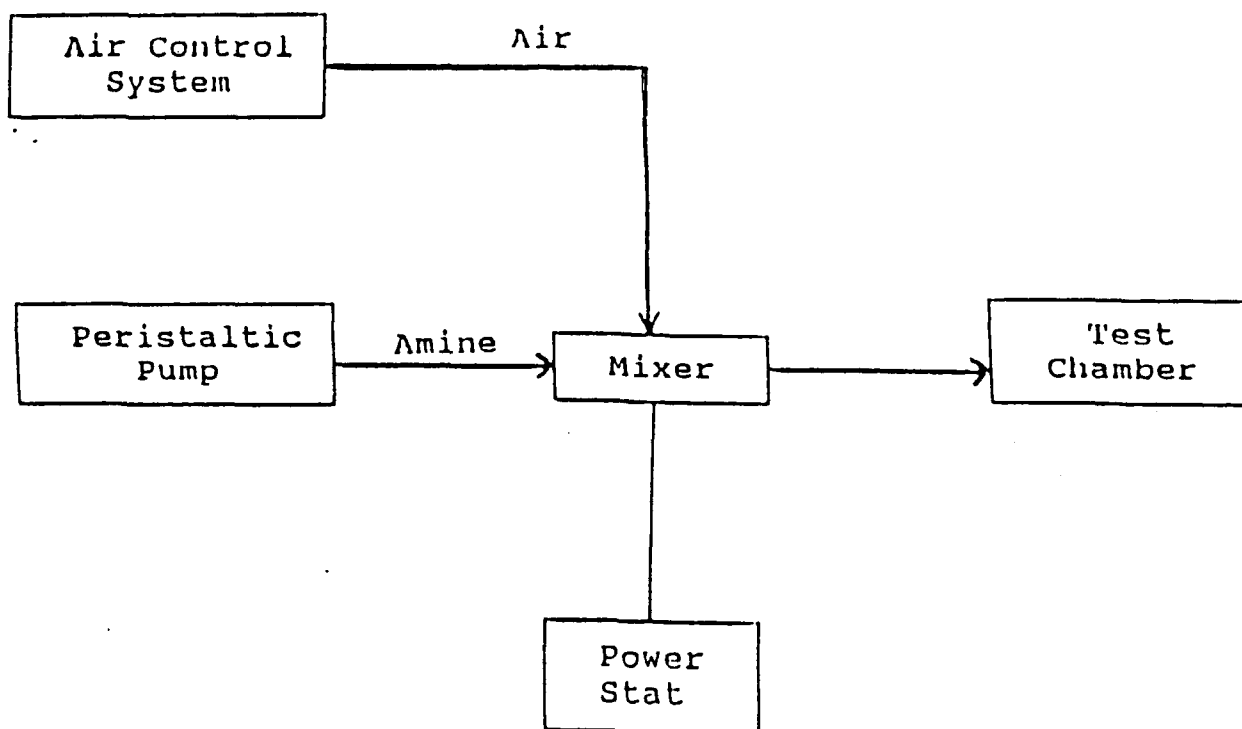


Figure 2: Schematic of the Apparatus Used

2.3.2 Testing

Two series of tests were carried out to determine the effect of the charcoal bed retainer design on the flow patterns inside the bed. In Series A, the plastic canister retainer was used (see Annex A, Figure A-3). In Series B, the C2 canister retainer was used (see Annex A, Figure A-4).

Series A and B were run at air flow rates of 30, 50 and 85 $\text{l} \cdot \text{min}^{-1}$. The experimental conditions are shown in Table 1. In addition, the following apply:

- All of the experiments were run at 80 % RH (in-coming air).

Exp. #	Pre-cond. (hrs)	Ret.	Air flow rate (lpm)	Amine flow rate (ml/min)	Air T _{in} (°C)	T _{amine} (°C)	R.H. (%)	Test time (min)
1	24	A	30	0.60	27.1	80.5	74	5.8
2	26	A	50	0.60	27.2	81.0	72	6.2
3	17	A	30	0.60	27.2	80.5	79	5.7
4	17	A	30	0.60	27.2	81.0	79	5.3
5	19	A	30	0.60	27.1	79.5	81	5.8
6	19	B	30	0.60	27.0	80.5	81	6.3
7	18	B	30	0.60	27.1	80.5	80	9.8
8	18	B	30	0.60	27.1	81.0	80	6.0
9	18	A	50	1.00	27.1	80.0	81	4.0
10	18	A	50	1.00	27.1	81.0	81	3.8
11	5	A	50	1.00	27.2	79.0	67	3.8
12	5	B	50	1.00	27.2	82.5	70	3.5
13	17	B	50	1.00	27.1	80.5	75	3.8
14	17	B	50	1.00	27.1	80.5	70	3.2
15	5	A	85	1.70	27.8	82.0	40	2.5
16	5	A	85	1.70	27.8	80.0	40	2.5
17	6	A	85	1.70	29.9	79.5	78	2.8
18	6	B	85	1.70	29.9	81.5	72	2.5
19	0	A ¹⁾	85	1.70	27.8	80.5	20	2.0
20	0	B	85	1.70	27.7	80.5	20	2.0
21	0	A	50	1.00	27.8	81.0	20	3.0
22	0	A	30	0.60	27.4	81.0	20	5.5
23	0	²⁾	85	1.70	29.0	79.5	25	2.0
24	0	³⁾	85	1.70	28.7	81.0	25	2.0

¹⁾ Retainer upside down.

²⁾ Without retainer.

³⁾ Without retainer and particulate filter.

Table 1. Summary of the test conditions.

- The amine flow rate was arbitrarily set at $0.6 \text{ l} \cdot \text{min}^{-1}$ for the $30 \text{ l} \cdot \text{min}^{-1}$ air flow. The amine flow rates were proportionately higher at flow rates of 50 and $85 \text{ l} \cdot \text{min}^{-1}$
- The temperature of the amine was determined to ensure a quick evaporation (bp. 55.5°C).
- The temperature of the incoming air was arbitrarily set.

3.0 RESULTS AND DISCUSSION

The results of the experiments listed in Table 1 are shown in Annex B. The effect of preconditioning the silica gel before running the experiment was discovered early. The canisters which were preconditioned for 17 hours or more tended to yield a light blue colour, which did not contrast well with the natural yellow colour (see Annex B, Figure B-2 and B-3). On the other hand, canisters that were conditioned for 6 hours or less, showed significantly more contrast, with the largest contrast being observed in the non preconditioned canisters (see experiment 23, Annex B). It was suggested that the preconditioning caused the moisture absorbed on the silica gel to react with the TBPE. This is illustrated in Figure 3. The 3',3'',5',5''-tetrabromophenolphthalein formed in the reaction is colourless. From that point on, the preconditioning time was changed from 17-24 hours to 5-6 hours.

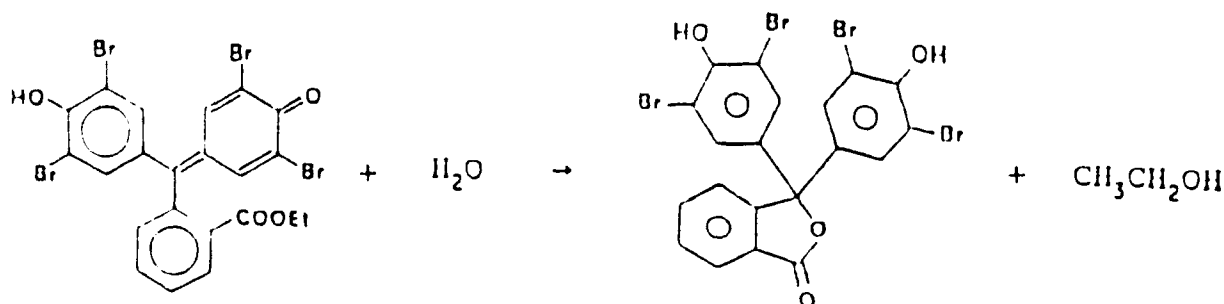


Figure 3: TBPE Reaction with Moisture

All of the canisters showed a uniform flow distribution across the canister diameter regardless of the flowrate (30, 50 or 85 litres per minute). This points unequivocally to the uniformity of the flow distribution through the charcoal bed of this particular canister design. Interestingly, the retainer design, plastic or metal, did not appear to have any effect on the flow distribution. It was thought that the metal retainer (C2 canister retainer),

whose holes begin approximately 10 mm from the edge of the canister, would have created a pocket of unused dye at the top of the bed, immediately underneath it. In the same vein, the plastic retainer was expected to allow better usage of the bed since the holes start at approximately 2 mm from the edge. At the same time, the very fact that the holes were so close to the edge of the canister prompted the question of whether the edge effect (looser packing at the wall of the canister which permits a larger flow of air) could be exacerbated by this. This concern was dispelled by the results. It is interesting to note that the differences between the two retainer designs did not seem to impact on the canister flow distribution. This observation seems to indicate that diffusion of the vapour is sufficient to ensure full use of the sorbent bed, even in areas outside the airstream such as between retainer holes. The number and size of the holes in the retainer are therefore probably more relevant to airflow resistance than to filtration efficiency, within reason.

Upon examination of the canisters, blue streaks were found in the silica bed which extended below the apparent line of colour change. Annex C contains the pictures of the various experiments conducted to study the problem. The best example of this phenomenon is shown in experiment #23 in Annex C (Figure C-1). The streaks were apparent around the walls of the canister as well as at the middle partition. Removal of the top layers of granules showed that they were also present at relatively regular intervals throughout the granular bed (see experiment #21, Annex C, Figures C-2 and C-3). These streaks were initially thought to be caused by accelerated flow velocity through the holes of the retainer. To verify this hypothesis, the plastic retainer was inverted so as to place the retainer's stiffening ribs against the charcoal bed, thereby creating a 3 mm gap. In this way, the airflow would be less concentrated locally at the bed/retainer interface. Results of that experiment were identical to the previous tests. Since the retainer holes were quite near the edge of the canister, it was thought that this could be the source of streaking on the side. Experiment #20 was conducted with a metallic retainer whose holes were distant from the edge. Streaking was also observed. Two more tests were carried out in which the components which could be responsible for channelling the flow were removed. In one case, the retainer was removed and in the other, both the retainer and the particulate filter were removed. Streaks were again observed. It was concluded that these components were not responsible for the streaks, and therefore the type of channeling that they could cause was not important enough to be noticeable.

Other possible causes of streaking were investigated, focusing on the bed assembly. The usual method of filling the C2 canister was used for these plastic parts i.e. snow flake filling. This ensures the most uniform density of the bed, and that no voids are created. The only difference in the bed assembly methods between the C2 canister and these prototype canisters was in the

compression of it. The C2 is compacted with a 1,500 N force. Unfortunately, it was not possible to apply a compaction force on the prototype canisters in these tests. Bed compaction favours a higher bed density and reduces the size of gaps between granules and at the wall. It is likely that the streaks observed in these tests were due to a loosely packed bed of silica gel.

During the preliminary stages of the experimental series, it was speculated that the wall across the centre of the canister might influence the flow distribution. It was thought that the wall effect would distort the airflow pattern leading to erroneous conclusions on the real distribution of the airflow. Two courses of action were considered: one in which a non-intrusive method could be used, and one to determine the extent of the wall effect by removing horizontal layers of granules down to the depth of the virgin granules looking for evidence of airflow pattern distortion.

In the first course of action, two techniques were investigated: the use of a freezing agent (liquid Nitrogen) to congeal the moist silica gel bed; and, the use of a transparent setting agent (polymethyl methacrylate, or PMMA). In both methods, the granular bed would be integral during the challenge by the diethyl amine. The post-treatment would permit the separation of the bed in two or more parts. The liquid nitrogen method failed because, even with lengthy pre-conditioning in humid air, there was not enough moisture to bind the silica granules together. The polyester or polymethyl methacrylate method also failed because the polymers or monomers dissolved the dye.

In the second course of action, layer upon layer of the reacted dye were removed with a spatula in a horizontal manner until the unreacted granules appeared. Using this technique, evidence of the wall effect would be visibly apparent. Although there was some evidence of wall effect on the middle partition (see Annex C, Figure C-3) there was no evidence of distortion of the cross-sectional pattern of flow distribution (Annex B, B-3). Therefore, it was concluded that it was not a problem.

4.0 CONCLUSIONS AND RECOMMENDATIONS

1) The method developed for these experiments on flow visualization has been a useful tool. From a methodology point of view, the best results were obtained with no R.H. preconditioning of the dye impregnated silica gel granules. Also, the middle partition used in the technique did not affect the cross-sectional flow distribution, although there may have been a small "wall effect".

2) The flow through the plastic canister was quite uniform and seemed to make efficient use of the bed, in spite of some minor channeling. Thus, the current basic design does not require modification.

3) Evidence of small leak paths (channeling) through the silica gel bed could not be correlated with the holes of the retainers or the pleating arrangement of the particulate filter. The channeling was, in all likelihood, caused by a lack of compaction of the granular bed which resulted in a non-uniform density.

4) The proximity of the retainer's holes to the wall of the canister did not seem to have an effect on the flow distribution even at the higher flow rates. Therefore, the number and size of holes are only of importance (within reason) to the breathing resistance of the canister. No change to the plastic canister retainer is required.

5.0 REFERENCES

1. D. Thoroval, J.W. Bovenkamp, R.W. Bets and B.V. Lacroix, Defence Research Establishment Ottawa Report No. 963, June 1987.
2. B.H. Harrison, R. Poirer, B. Zanette and F. Villeneuve, Defence Research Establishment Ottawa Technical Note 84-16, October 1984.

ANNEX A
EXPERIMENTAL SET-UP

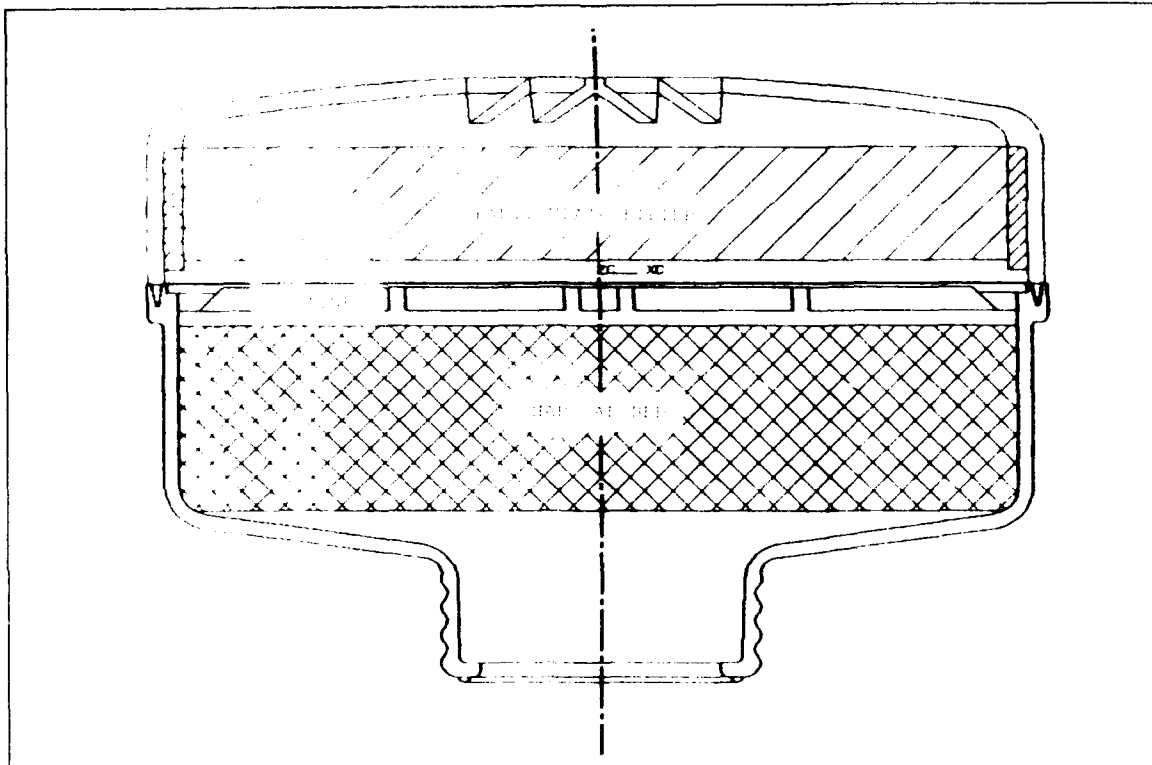


Figure A-1 Cross section of the plastic canister.

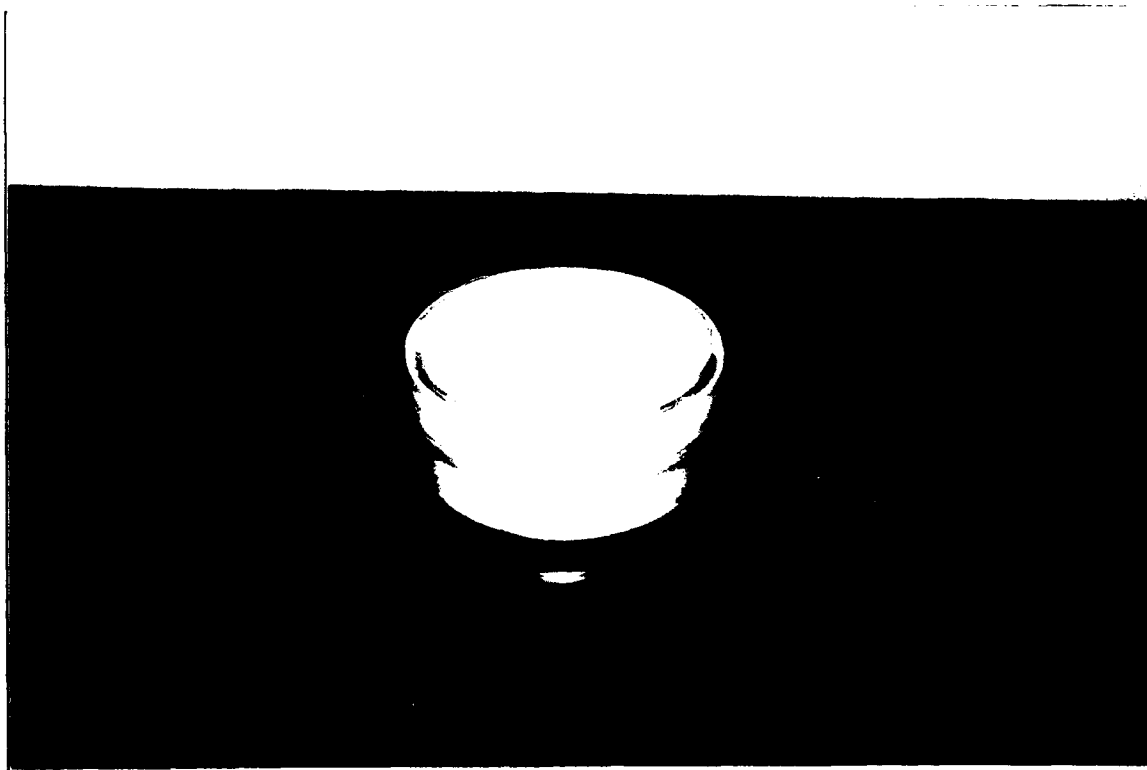


Figure A-2 Assembled canister, as tested.

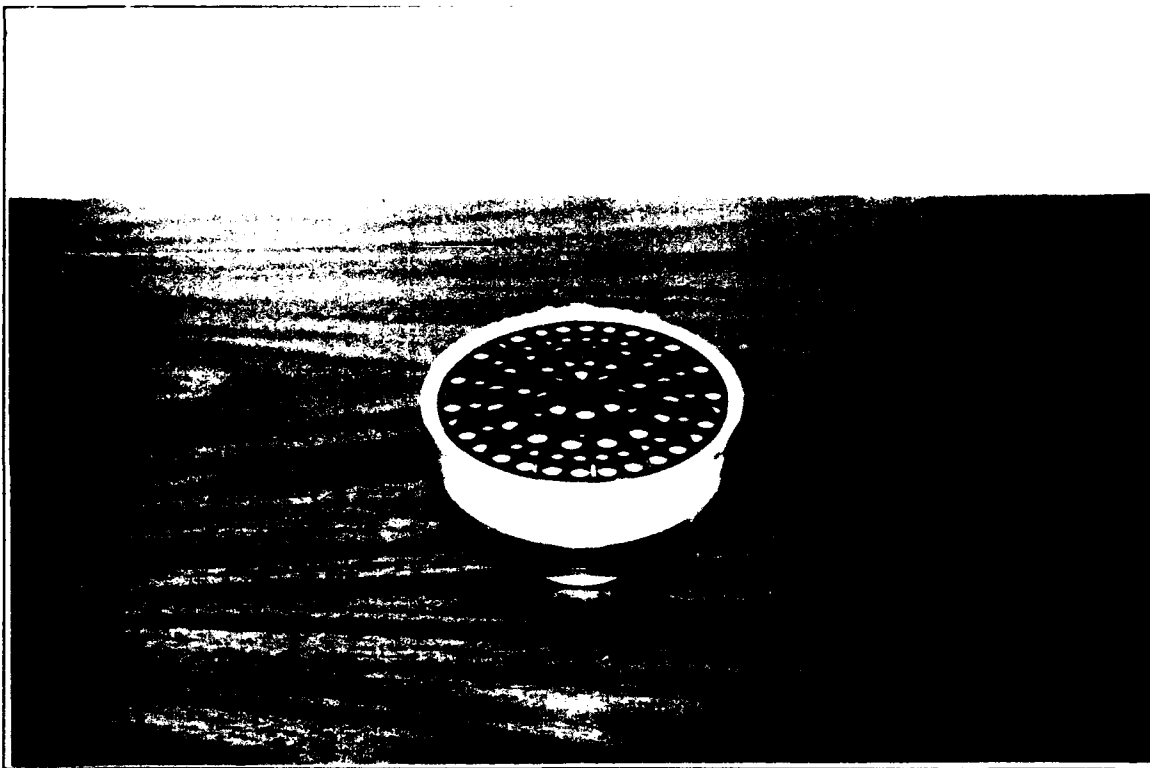


Figure A-3 The canister body with plastic canister retainer.

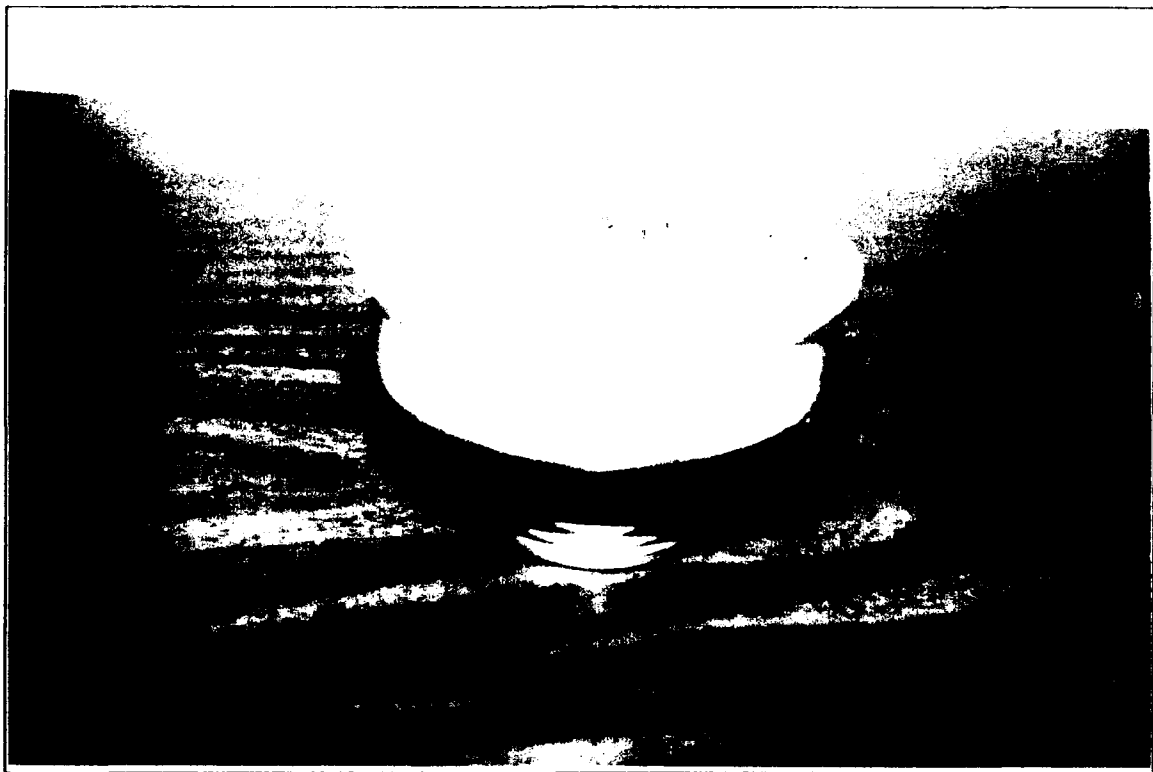


Figure A-4 Canister body with C2 metal retainer.

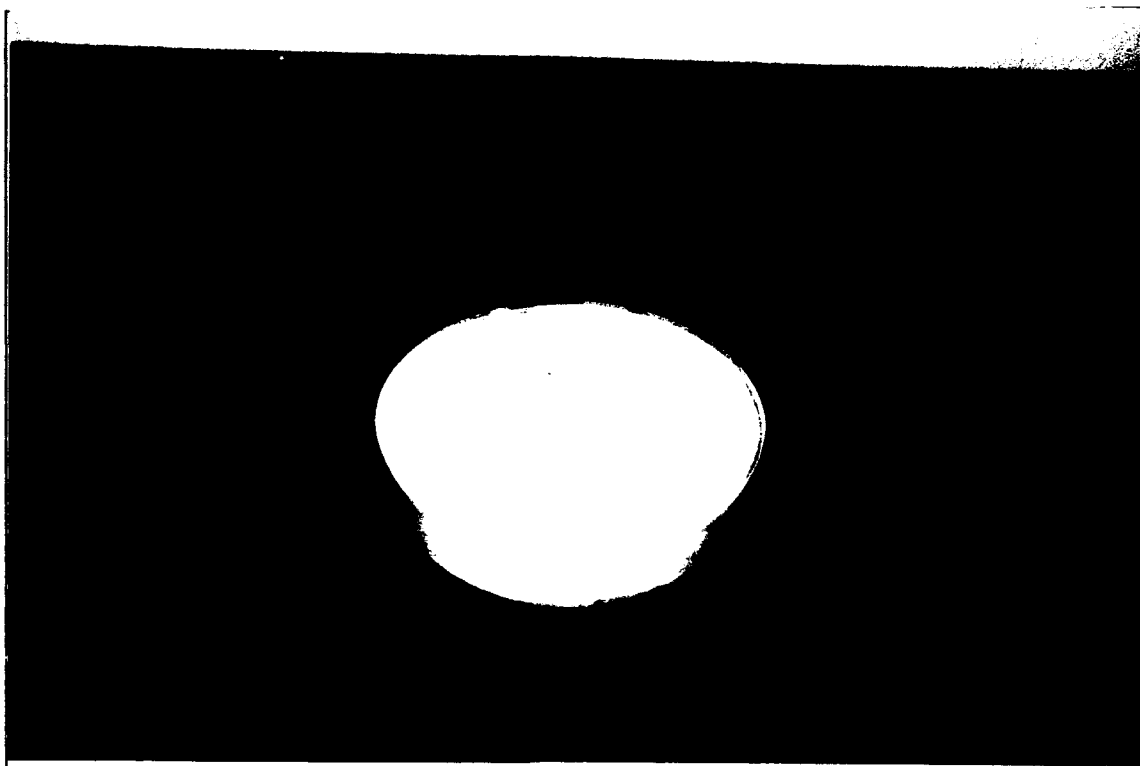


Figure A-5 Dye coated silica gel with middle partition.

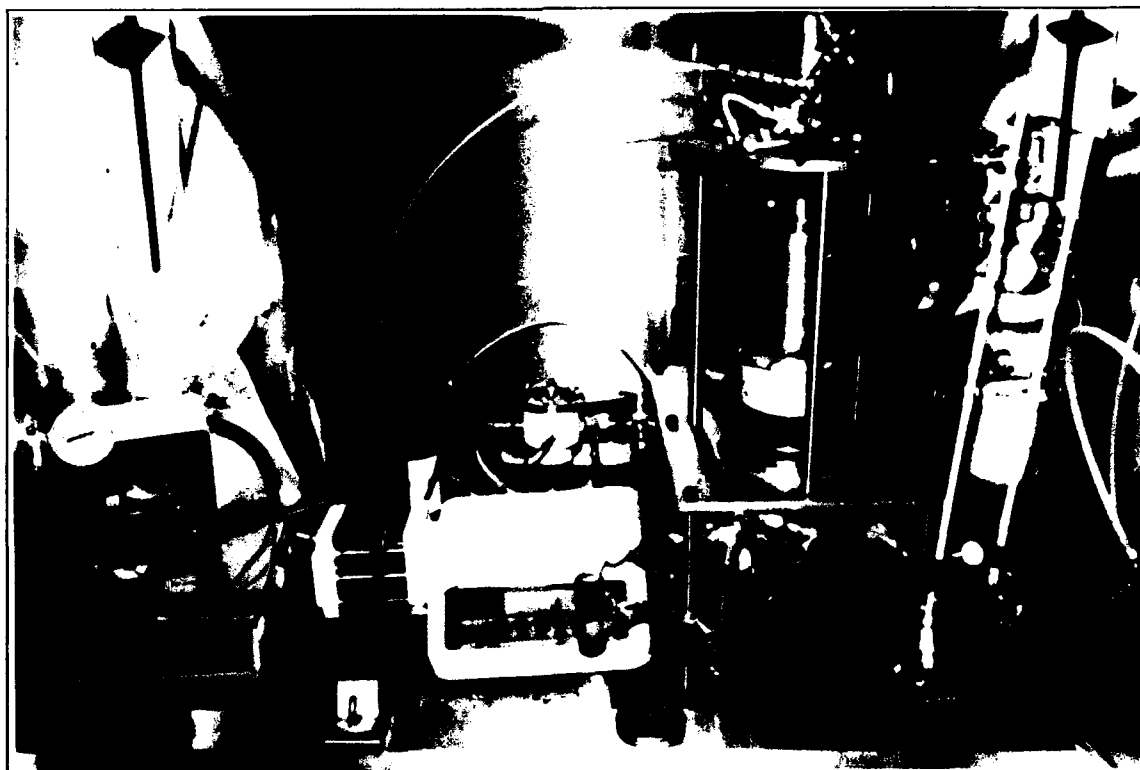


Figure A-6 The experimental set-up.

ANNEX B
FLOW DISTRIBUTION CROSS-SECTIONS



Figure B-1 Experiment #1



Figure B-2 Experiment #20

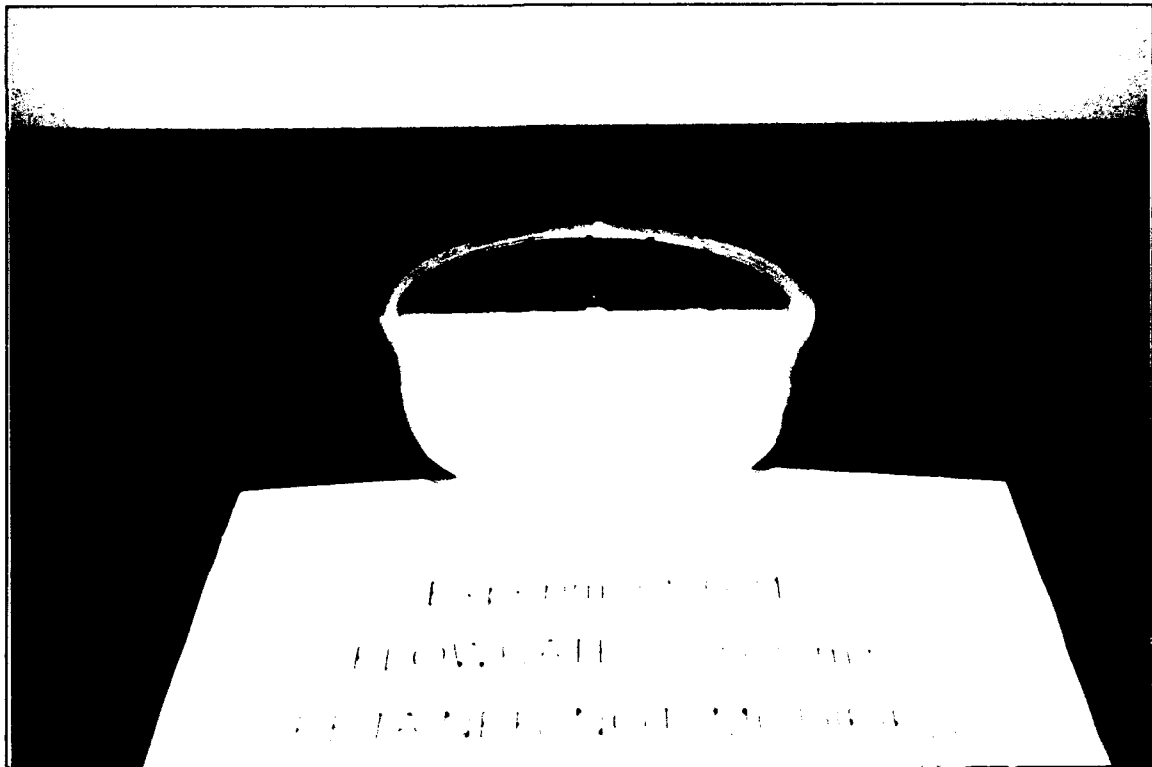


Figure B-3 Experiment #21

ANNEX C
FLOW CHANNELING

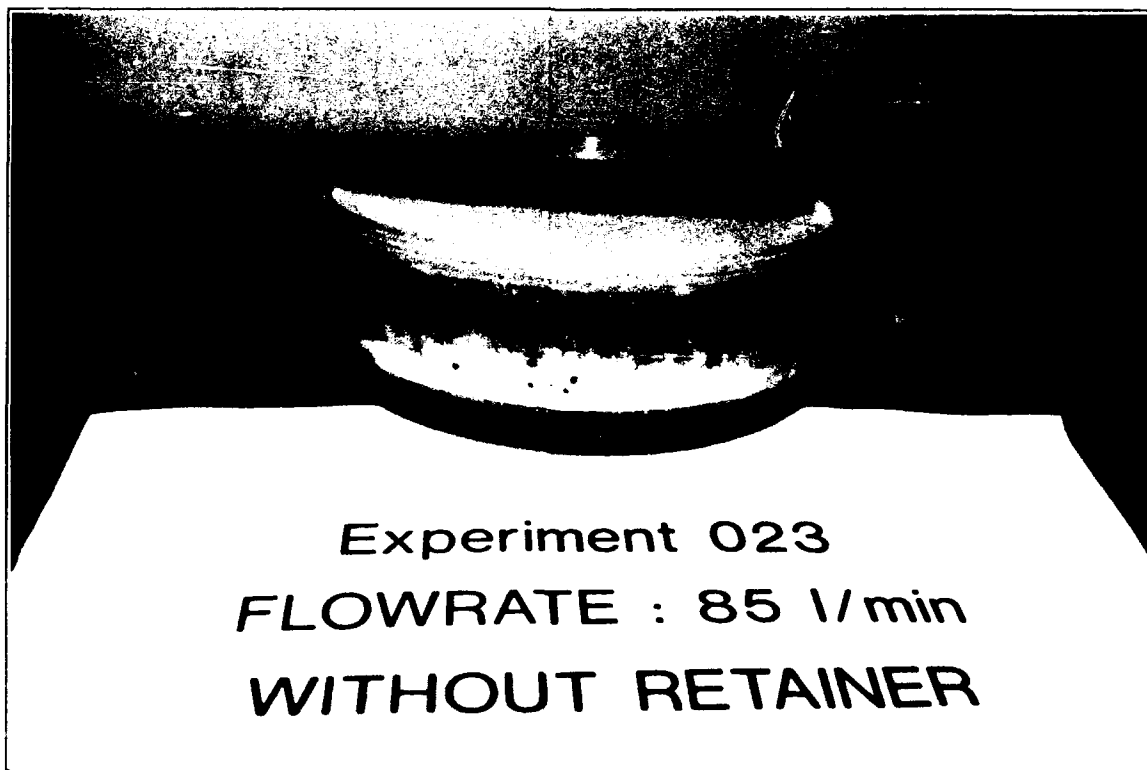


Figure C-1 Experiment #23

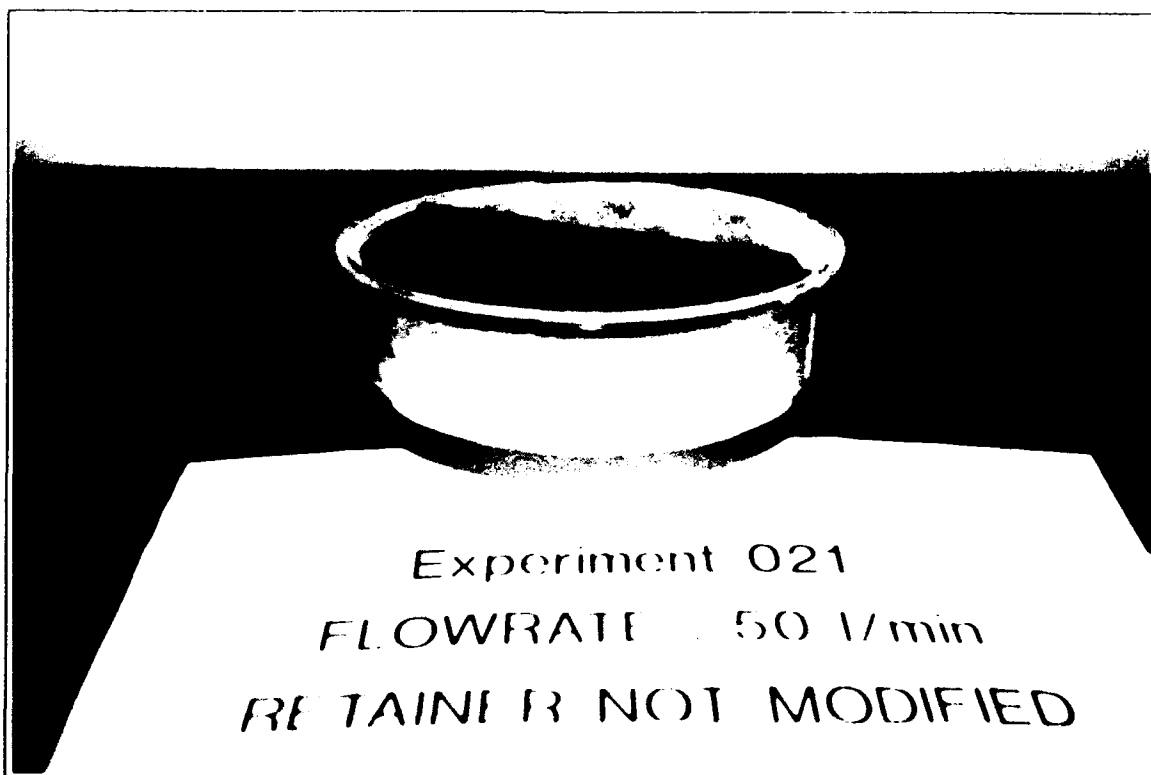


Figure C-2 Experiment #21

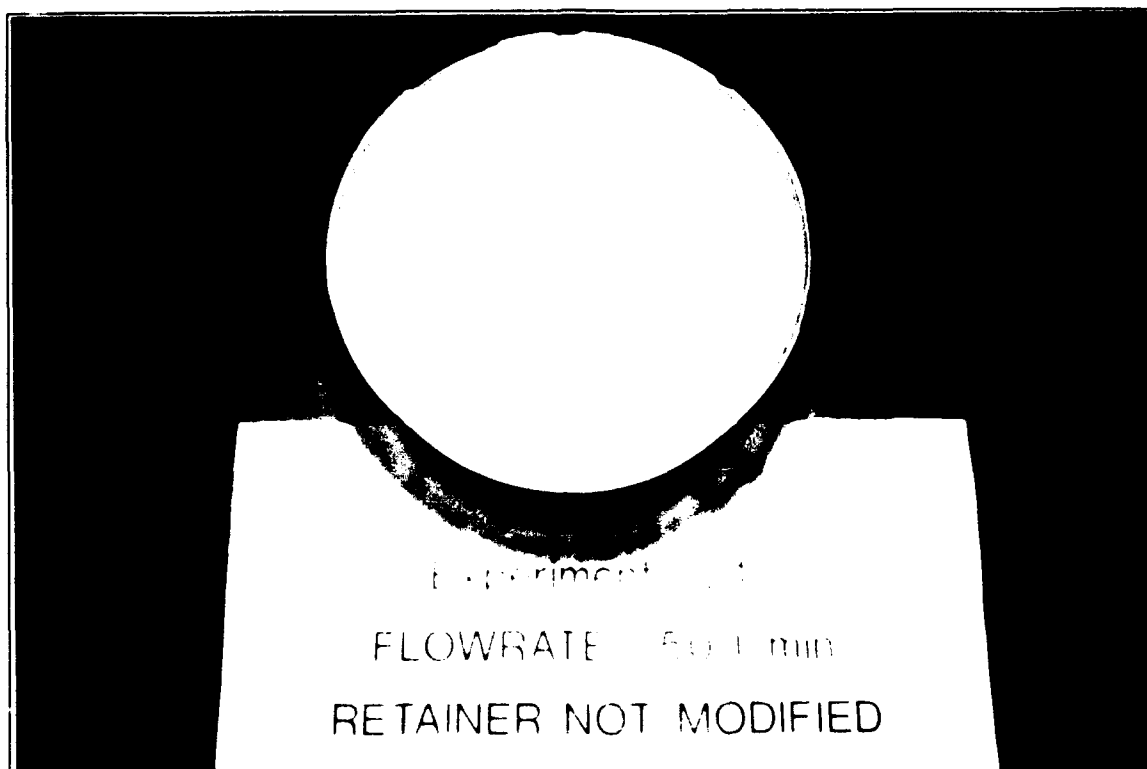


Figure C-3 Experiment #21

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A method of visualizing the airflow distribution inside a charcoal filter canister was developed to study the new plastic canister design. The method uses silica gel (of the same size as the charcoal used in the canister) coated with an acid/base dye which discolours from yellow to a dark blue. The depth of the reacted dye is a direct representation of the flowrate. A technique to observe the cross-section of the canister was developed, and canisters were subjected to various flowrates in different configurations. It was found that the current plastic canister design is sound, and that its uniform flow distribution will ensure optimal use of the charcoal and thus the highest efficiency. The retainer designs evaluated (the current C2 canister retainer and that of the new plastic canister) did not seem to have an effect on the flow distribution.

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